MINERALIZATION IN CAPE MONACO, ANVERS ISLAND AND FALSE BAY, LIVINGSTON ISLAND, FROM GLACIALLY-DERIVED SEDIMENTS

A Thesis

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by

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ABSTRACT

Fine glacially-derived sediment samples were collected in 1981 from the Cape Monaco area of Anvers Island and the False Bay area of Livingston Island. The samples were taken down "glacial stream" from the ice fronts of glaciers on both islands. The samples have been sieve separated, run through Bromoform, and examined microscopically in transmitted and incident light. The study was done to gain insight into rock composition and to the possible existence of anomalous mineralization up glacial stream from the sample locations.

The secondary hydrothermal alternation products sericite, chlorite, and epidote were noted at both sample locations. Metallic minerals present include, in order of abundance, magnetite, hematite (after magnetite), sphalerite, pyrite, chalcopyrite and galena. Common rock-forming minerals present in the samples include quartz, plagioclase, biotite, augite, and hornblende, plus tremolite. The samples from both the Cape Monaco and False Bay areas have compositions similar to Andesite.

ACKNOWLEDGMENTS

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Chapter I

INTRODUCTION

Anvers Island is located about 20 miles west of the Antartic Peninsula (Figure 1). With an area of about 1000 square miles, Anvers Island is 40 miles at its longest and about 30 miles wide. Mount Francais (9060 ft.) is the highest landform of the island, followed by Mount Moherly (5250 ft.).

Rocks of the island are Upper-Jurassic in age and include diorite, tonalite, trondhjemite, trondhjemite-porphyry, quartz-diorite porphyry, and granite-granodiorite (Hooper, 1962; Moody, 1982). These rocks are part of the Andean Intrusive Suite of Tertiary age (Moody, 1982). Large portions of the island are covered by ice (Figure 2). Weathering of rock material to regolith is minimal, and vegetation where present, consists of mosses and lichens (Moody, 1982).

Livingston Island is part of the South Shetland Islands group, which lie about 100 miles northwest of the Antartic Peninsula (Figure 3). Livingston Island and the other islands of the South Shetlands group are covered largely by ice. Livingston Island is the second largest of the South Shetland Islands. It is 47 miles long and 19 miles wide, with a low flat-lying western portion and mountainous relief in the False Bay area.

Rock types in the False Bay area consist mainly of tonalite from the Andean Intrusive Suite and hornblende schist and biotite schist of the False Bay Schists (Hobbs, 1962). The age of the False Bay Schists is believed to be Precambrian (Curl, 1980).

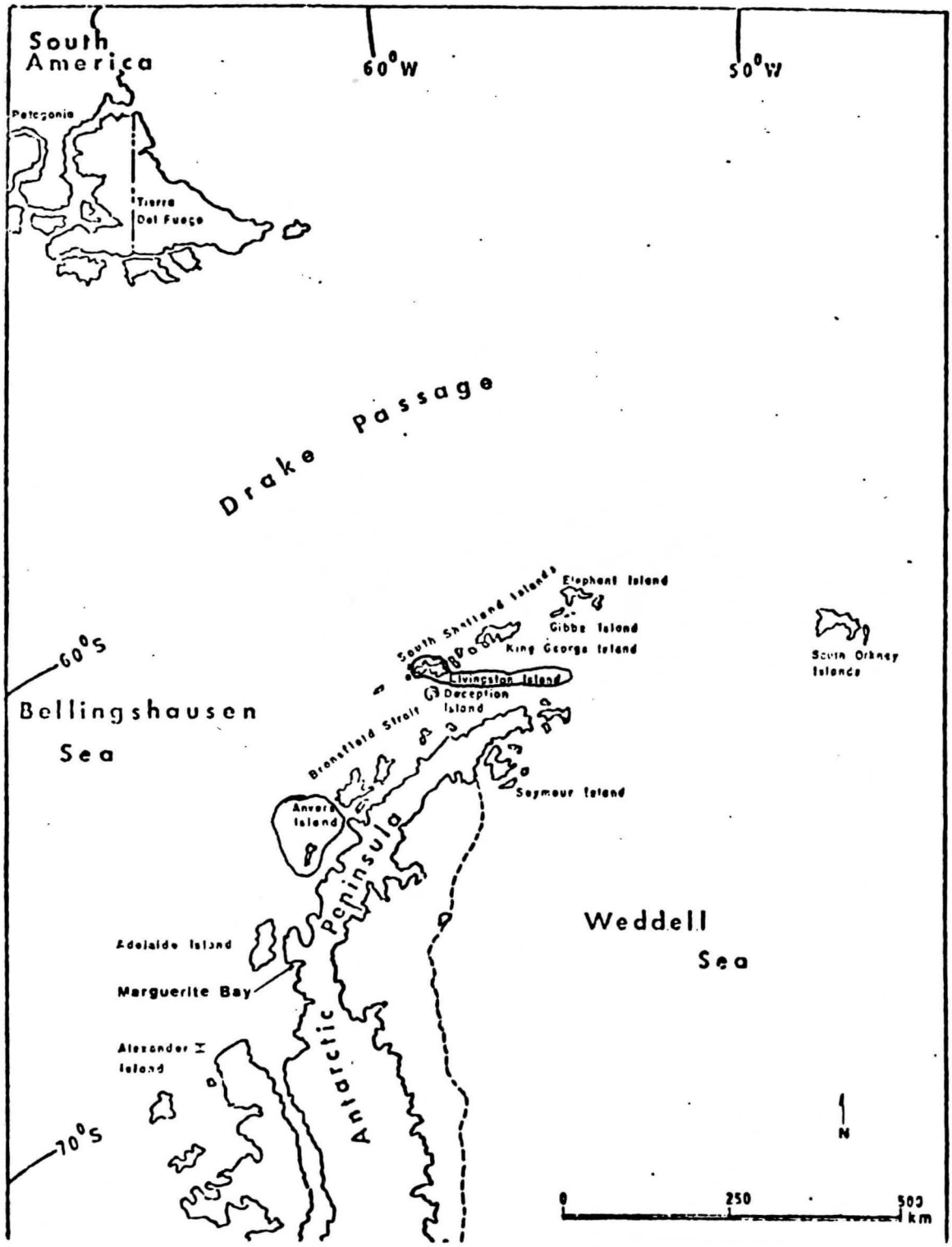

Fig. 1. Index map of the Northern Antarctic Peninsula and South America.

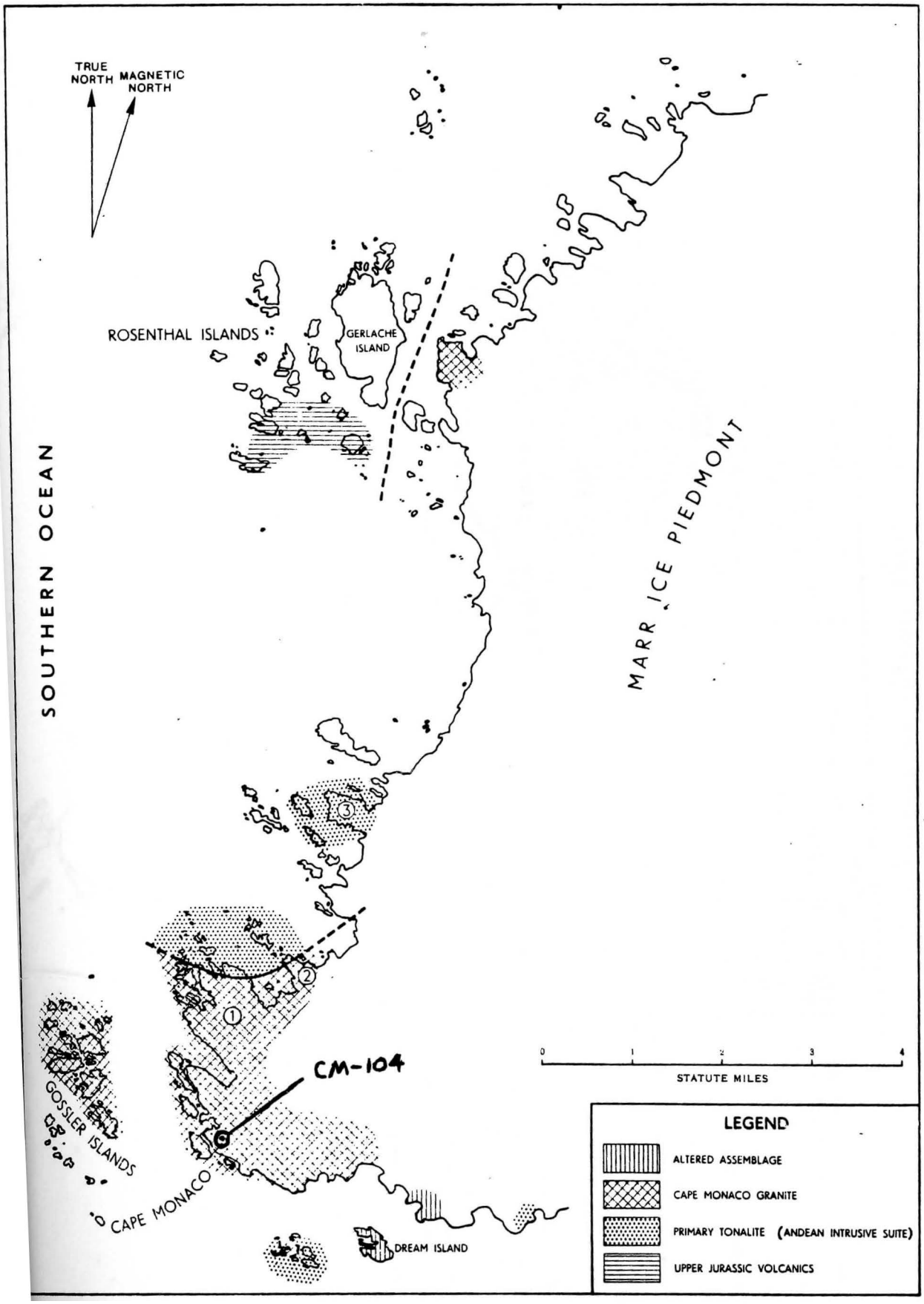

FIGURE 2
Geological map of the south-west coast of Anvers Island.

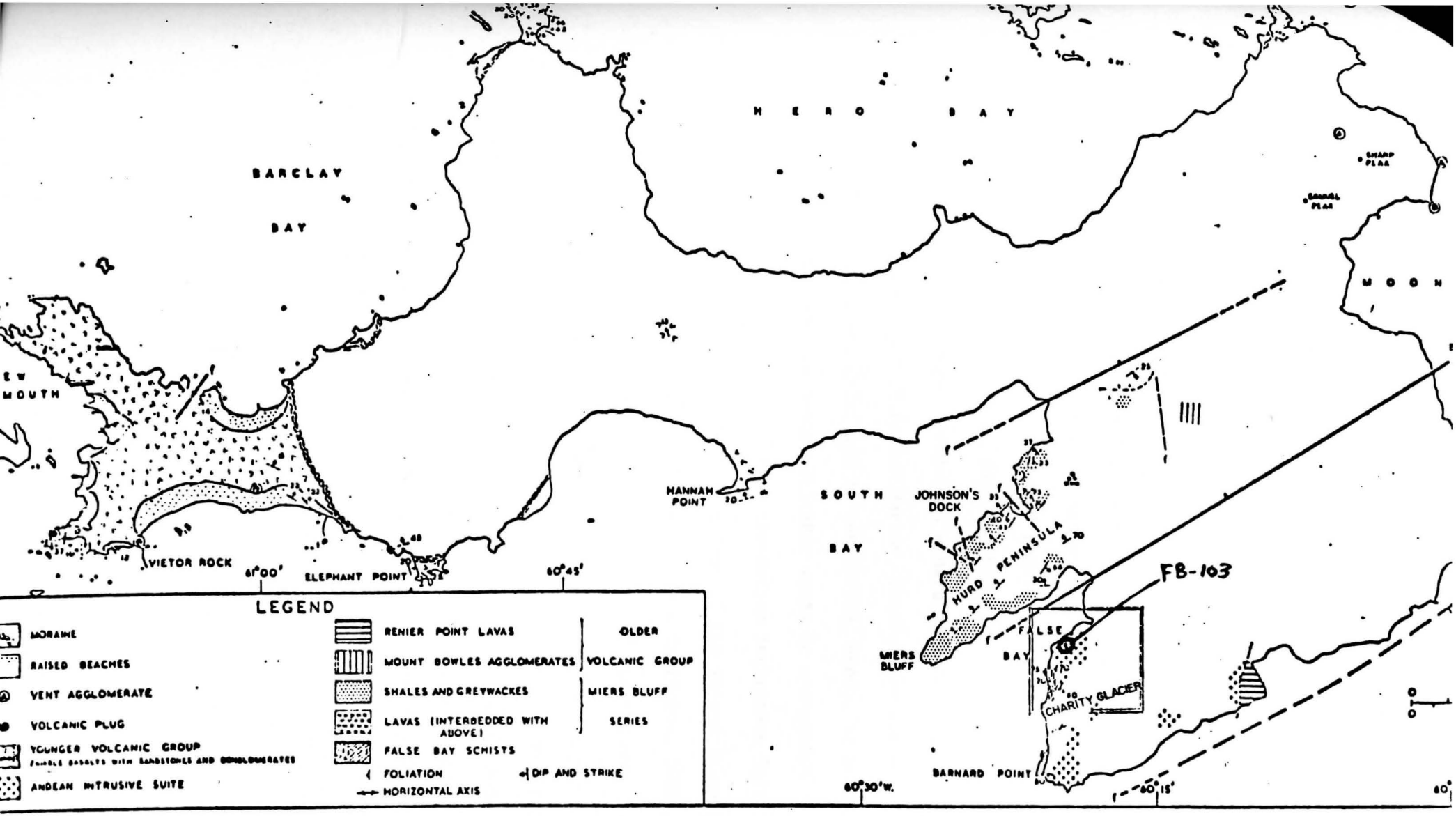

Figure 2. Geologic map of Livingston Island, South Shetland Islands (from Hobbs, 1968). The general area of interest east of False Bay lies within the outlined region.

Chapter II

GEOLOGY OF CAPE MONACO AND FALSE BAY

The Cape Monaco area of Anvers Island is known for its distinctive granite. A gradual transition from granite to "dark rock" occurs between Bonnier and Giard Points. The Cape Monaco Granite consists of large crystals of quartz and a finer matrix of feldspar. Other components include chlorite, biotite, and hornblende (Hooper, 1962). Anomalous mineralization at Cape Monaco to the southeast of Arthur Harbor, consists of copper, molybdenum lead, zinc, gold, and silver (Pride, Moody, in press).

Rocks examined from around volcanic vents on Livingston Island contain tonalite blocks from the Andean Instrusive Suite. This might indicate that a greater portion of the island is underlain by tonalite than outcrop data would indicate (Hobbs, 1968). Tonalite fragments found in the volcanics contain quartz and plagioclase as well as alteration products such as penninite, calcite, quartz, epidote, and leucoxene (Hobbs, 1968). Metallic mineralization includes pyrite, molybdenite, chalcopyrite, and sphalerite (Pride, et. al., 1981). The False Bay area is also noted for hornblende schist and biotite schist of the False Bay Schists (Hobbs, 1968).

Chapter III

PURPOSE

The goals of the present study of Cape Monaco, Anvers Island, and False Bay, Livingston Island are:

1) To provide insight as to the possible existence inland of anomalous alteration and mineralization beneath the ice at the two localities.
2) To provide petrologic information on rock types that may exist up glacial stream in the Cape Monaco area of Anvers Island, and the False Bay area of Livingston Island.

Chapter IV

PREVIOUS WORK IN THE ANVERS AND LIVINGSTON ISLAND AREAS

In 1897, de Gerlache conducted the first scientific expedition of Anvers Island in his ship Belgica. H. Arctowski was the expedition geologist, and he made observations of glaciology as well as systematically collecting rock specimens (Adie, 1957). A. Pelikan (1909) and Sistek (1912), chemically analyzed the specimens collected on the de Gerlache expedition. Pelikan produced the first geologic map of the area. Charot (1903-05 and 1908-10), and E. Gourdon (1905,1906,1907,1908,1917), explored Anvers Island and nearly Booth Island (Hooper, 1962). Gourdon (1917) studied the petrology of rocks from the island, noting the existence of quartz-diorite containing a large number of basic inclusions. D. Ferguson (1921) collected fine-grained sedimentary rocks which he considered to be Jurassic in age. G. W. Tyrrell (1921) noted the abundance of volcanic rocks among the specimens collected by Ferguson. O. Holtedahl (1929) gave an in depth report on the physiography and geomorphology of the Danco Coast and Palmer Archipelago.

In 1981, Dr. D. E. Pride, M. Rosen, and S. Moody collected samples from Cape Monaco, from the Arthur Harbor area, and from the surrounding islands. These samples were analyzed for copper, lead, zinc, molybdenum, silver, gold, tungsten, and fluorine. The samples also were studied in thin section and polished surface,

to identify rock types and to document alteration and mineralization in the southern Anvers Island vicinity. These studies identified high temperature hydrothermal veining near Palmer Station (U.S.A.). Moody (1982) concluded that the mineralization in the Arthur Harbor area may be peripheral to a porphyry copper system of the Lowell and Guilbert type (Lowell and Guilbert, 1970). The system may be present beneath the ice to the east of Palmer Station.

Livingston Island, South Shetland Islands

The South Shetland Island were discovered in 1819 by Captain William Smith on a voyage by the William. Livingston Island was first noted by sealers in 1821 when they discovered the remains of a spanish gallion on Half Moon Beach. J. G. Anderson was the first geologist to explore Livingston Island in 1902 (Hobbs, 1968). Although be collected numerous specimens from the area, all were lost when his ship, the Antarctica, sank in the Weddell Sea in 1903 (Hobbs, 1968). Between 1913 and 1914, Ferguson investigated the petrology and physiography of Livingston Island (Hobbs, 1968). Ferguson noted numerous volcanic vents, mudstone, and diorite ejecta on the island. G. W. Tyrrell reported on the petrology of the specimens collected by Ferguson in 1921 (Hobbs, 1968). O Holtedahl briefly described the topography of the island while sailing by in 1927 (Hobbs, 1968).

G. J. Hobbs conducted detailed geologic studies on Livingston Island in 1957 and 1958. A number of rock specimens were examined and colected during these visits including specimens from Edinburgh Hill, an olivine-basalt plug. The rocks of the island range

from Precambrian to late Tertiary in age, and range in composition from sedimentary rocks to metasediments, volcanics, and the Andean Intrusive Suite of Late Cretaceous to Tertiary age (Curl, 1980). The False Bay Schists are the oldest rocks present but are exposed over only a small portion of the island. Recent geologic studies conducted by Everett (1971) indicate that Livingston Island underwent 3 major periods of glaciation.

Chapter V

GLACIAL DISPERSION

Glacial dispersion can be regarded as the removal of some component or components of bedrock by glacial ice and the subsequent transportation of this material by ice or glacial stream to a site of deposition (Shilts, 1981). The frequency of occurrence of some component decreases exponentially with distance from the source.

The lithology and topography of the source area dictate the types and amount of material available for transport (Shilts, 1981). The region of dispersal also may contribute to the glacial sediment. High areas anywhere along the path of the glacier probably will contribute more material than flattened areas. Low areas may be more highly altered and the material there would be more easily eroded. Therefore topographic variation would tend to contibute more rock material to the till then flat areas, even if rock material present in the high and low areas is less significant in terms of total representation of mineralization of a particular area. The manner in which the glacial debris was transported to the site of deposition. For example, movement by ice versus glacial stream can dictate the sizes of material present and the degree of sorting. Finer material in stream transported material, may be represented at the glacial front while coarser material may be deposited farther up glacial stream beneath the ice front. Glacial crushing and abrasion may lead

to the concentration of harder less cleavable rock material in the coarser fractions and the concentration of softer and/or more friable material in the finer fractions.

It is important for one to consider factors such as sediment size, specific gravity, type of transport, and topography of dispersal area, when conducting petrologic studies of glacial debris.

Chapter VI

FIELD STUDIES

The study samples were collected in 1981 by Dr. Douglas Pride from the Cape Monaco area of Anvers Island and from the eastern False Bay area of Livingston Island. The samples were labeled CM-104 and FB-103 respectively. The samples then were transported to the Ohio State University where they were processed for study.

Chapter VII

LABORATORY STUDIES

The samples used in this study first were dried, then sieved and weighed. A diagram outlining the laboratory procedure is shown in Figure 4. The samples were sieved through screens of mesh sizes 16, 32, 65, 115, 250 and the minus 250 material was caught in the pan. The sieve fractions then were weighed and the weights of these fractions were combined and compared to the original unsieved weight of the sample to determine the amount of sample lost during sieving (Tables 1 and 2).

Bromoform was used to separate the sieve fraction into "float", "sink", and "suspend" fractions, for each mesh size. Grains with a specific gravity less than Bromoform float to the surface and were saved for later study. Grains with considerably higher specific gravities than Bromoform sink to the bottom, while those grains of combined light and heavy minerals remain suspended within the Bromoform. Ten suspended and 14 sink fractions then were impregnated and made into thin sections and polished surfaces.

A Leitz Laborlux II Pol polarizing light microscope was used to identify mineral phases in thin section, and point counts were made to determine the volume percent of each component. The opaque phases could not be identified and thus were grouped simply as "opaques". The spacing of counts ranged from 0.01 mm in the m 250 and m > 250 fractions, to 0.06 mm in the m 16 (sink only) and m 32 fractions. The intent of the spacing is

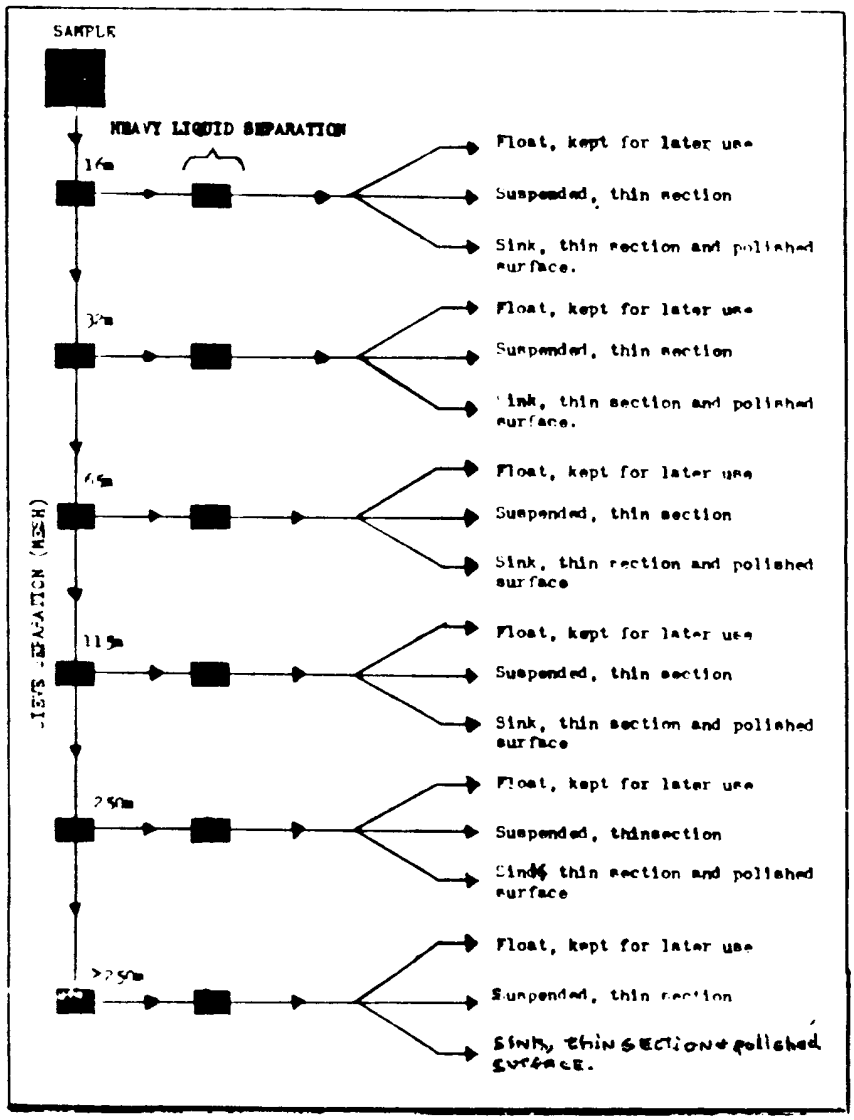

Figure. 4 Flow Chart of Sieve and Heavy liquid seperation.

SAMPLE NO.- CM-104

MESH SIZE	Total Weight	"Sink"	"Suspend"	"Float"
MESH 16	13.2929	0.8167	included in sink	12.4762
MESH 32	39.4669	0.5068	0.0589	38.9012
MESH 65	65.7917	1.0837	0.2546	64.4534
MESH 115	56.5912	1.1711	0.4234	54.9967
MESH 250	65.8170	3.0376	0.7007	62.0787
PAN (>250)	121.1320	1.1777	0.7485	119.2158

GRAND TOTAL = 362.1017

Table 1.

SAMPLE NO.- FB-103

MESH SIZE	Total Weight	"Sink"	"Suspend"	"Float"
MESH 16	52.0091	0.5395	included in sink	51.4696
MESH 32	68.0359	0.6941	0.1538	67.1880
MESH 65	308.3628	4.5939	0.6691	303.0998
MESH 115	82.7562	4.1807	0.5322	78.0433
MESH 250	55.5733	4.5091	2.2321	48.8321
PAN (>250)	31.7343	0.2377	1.5349	29.9617

GRAND TOTAL = 598.4716

Table 2.

to encounter a minimum number of "holes", (non-mineral stops) and a maximum number of grains. "Holes" were not figured into the volume percent calculations.

The number of grains counted in each thin section ranged from 103 to 593. Representative passes were made through the center of those sections, with very large numbers of grains.

A Reichert incident light microscope was used to examine polished surfaces. Between 289 and 355 grains were counted from each surface. The opaque phases constitute only a fraction of the total grains present in the surface, and these counts of opaques were made by examining a given field of view and counting all opaques present in the field. As in the thin section study, representative counts were made of the finer size fractions.

Chapter VIII

THIN SECTION ANALYSIS

The volume percents for each mineral present in each size fraction for CM-104 suspend and FB-103 suspend are given in Tables 3 and 4, respectively. The volume percents for each mineral present in each size fraction for CM-104 sink and FB-103 sink are given in Tables 5 and 6, respectively. As expected, the suspend and sink fractions from the Cape Monaco area are quartz poor. The average quartz composition dropped from 8.2% to 2.3% from suspend to sink fraction. The quartz present in the sink fractions usually is attached to heavier minerals as hornblende (specific gravity, 3.0-3.4) and opaque phases like magnetite (specific gravity, 5.18).

The average plagioclase content also drops from 40.6 to 27.1 percent from suspend to sink fractions. The percentage of amphibole increases from 21.7 to 32.4 percent in suspend and sink fractions. The relative composition of all mineral phases in both suspend and sink fractions are fairly consistent from mesh 16 to mesh 115, but exhibit a radical change in the mesh 250 and > 250 range.

The False Bay samples are extremely quartz poor. The plagioclase content decreases from suspend to sink fractions (36.1 to 27.2 percent), and from larger to smaller mesh sizes. The most obvious difference between FB-103 suspend and FB-103 sink is in amphibole content, which nearly doubles from suspend to

TABLE 3

Volume percents of CM-104 Suspend.

Sample No. CM-104-Suspend	Volume percent of each mineral present in each grain size.						Average Percent
Mineral	m 16	m 32	m 65	m 115	m 250	m >250	
Quartz	No Sample	11	13	4	10	3	8.2%
Plagioclase	"	29	37	48	42	47	40.6%
Biotite	"	9	10	6	1	0.5	5.3%
Augite	"	8	6	6	3	4	5.4%
Hornblende	"	19	18	21.3	22	28	21.7%
Tremolite - Actinolite	"	?	1	3.7	0.4	0	1.4%
Opaques	"	6	8	5	10	12	8.2%
Epidote	"	3	3.5	3	6	1	3.3%

TABLE 4

Volume percents of FB-103 Suspend.

Sample No. FB-103 Suspend	Volume percent of each mineral present in each grain size.						Average Percent
Mineral	m 16	m 32	m 65	m 115	m 250	m >250	
Quartz	NO Sample	1	0	0	0.5	8	1.9%
Plagioclase	"	45	38	34	27.5	36	36.1%
Biotite	"	0.5	1	0.5	0	0	0.4%
Augite	"	1.5	1	1	1	1	1.1%
Hornblende	"	11	7	11	16.3	30	15.1%
Tremolite - Actinolite	"	1	2	2.5	1.7	1	1.6%
Opaques	"	38	47	48	51	20	40.8%
Epidote	"	0.5	1	1	0	2	0.9%

TABLE 5

Volume percents of CM-104 Sink.

Sample No. CM-104 Sink	Volume percent of each mineral present in each grain size.						Average Percent
Mineral	m 16	m 32	m 65	m 115	m 250	m >250	
Quartz	4	2	3	4	0.5	0	2.25%
Plagioclase	52	25	36	35	7.5	7	27.10%
Biotite	4	8	3	6	2	0	3.80%
Augite	2	2	7	9	7	6.5	5.60%
Hornblende	30	21	29	28.6	45	40.5	32.40%
Tremolite - Actinolite	0	1	11	3.4	16	16.5	13.10%
Opaques	3	29	4	6	14	25.5	13.60%
Epidote	0.3	7	1.3	2.7	4	1.5	2.80%

TABLE 6

Volume percents of FB-103 Sink.

Sample No. FB-103 Sink	Volume percent of each mineral present in each grain size.						Average Percent
Mineral	m 16	m 32	m 65	m 115	m 250	m >250	
Quartz	0	2	0.6	0	2	0	0.77%
Plagioclase	43	39	29	30	10	12	27.20%
Biotite	0	0.3	0.4	0	0.4	0	0.18%
Augite	2	3.7	5	2	1	1.5	2.50%
Hornblende	19.5	29	29.5	43.6	48	34	34.00%
Taemolite - Actinolite	3.5	2	8.5	3.4	1	2	3.40%
Opaques	28	21	23	19	31	49	28.50%
Epidote	0	0.7	2	1	5.3	1.1	1.70%

sink fractions (15.1 to 34, percent).

In addition to the characteristics noted, the Cape Monaco sink fractions are rich in opaques, principally magnitite. The percentage of opaques in the False Bay sections is much higher in the suspend fractions than in the sink.

The composition of plagioclase was measured by the "Michel-Levy" method. The grains with well-developed twin planes were examined from each area. The measurements are given in Tables 7 and 8. The average anorthite composition for CM-104 is 33.6, and for FB-103 is 37.6. In both cases the anorthite content is that of andesine (AN 30-50) (Kerr, 1977).

Alteration products from Cape Monaco and from False Bay include: sericite after plagioclase, alteration of hornblende to chlorite, and sometimes partial to complete alteration of biotite to chlorite. Secondary epidote also was noted in all sections except FB-103 sink m 16 and FB-103 suspend m 250. Highly fractured masses of rock fragments containing hornblende, plagioclase, chlorite, sericite, and epidote were observed in the m 16,32, and 115 size fractions. The original composition of the fragments probably was hornblende and plagioclase, which were altered by hydrothermal fluids to sericite (after plagioclase), chlorite (after hornblende), and secondary epidote. The Cape Monaco specimens in particular exhibit considerable alteration of both hornblende and plagioclase.

Chapter IX

POLISHED SURFACE ANALYSIS

The sink fractions of CM-104 and FB-103 were examined using a Reichert NR 340075 incident light microscope. Magnetite was by far the most abundant opaque phase found in the surfaces, followed in abundance by hematite, sphalerite, pyrite, chalcopyrite and galena. Galena was observed only in the Cape Monaco samples. Pyrite was very scarce in both the Cape Monaco and False Bay samples (1.5 and 0.8% respectively). Hematite probably formed as an alteration of magnetite, and it was usually observed peripheral to magnetite or as discrete grains. Volume percents of CM-104 sink and FB-103 sink for polished surfaces are shown in Tables 9 and 10, respectively.

SAMPLE NO. ~~CM-104~~ (Sink)

Metallic Mineral	MESH SIZE, POLISHED SURFACE						Average Percent
	16	32	65	115	250	>250	
MAGNETITE	92	NO Sample	82	85	77	87.5	84.7%
HEMATITE	5.5	"	12.3	6.6	8.2	6.3	7.8%
CHALCOPYRITE	2.5	"	2	0.5	1	0.9	1.4%
PYRITE	0.0	"	0.7	1	3.6	2.3	1.5%
SPHALERITE	0	"	2.7	6.9	9	3	4.3%
GALENA	0	"	0.3	0	1.2	0	0.3%

TABLE 9

Volume percents of CM-104 Sink.

SAMPLE NO.-FB-104 (Sink)

Metallic Mineral	MESH SIZE, POLISHED SURFACE						Average Percent
	16	32	65	115	250	>250	
MAGNETITE	77	86.7	74	77.5	76	93.5	80.8%
HEMATITE	18.5	13.3	24	16.6	19.5	1.9	15.6%
CHALCOPYRITE	4.2	0	0	0.5	1	0.6	1.0%
PYRITE	0.3	0	0.6	3.1	0.3	0.9	00.8%
SPHALERITE	0	0	1.4	2.3	3.2	3.1	1.8%
GALENA	0	0	0	0	0	0	0.0%

TABLE 10

Volume percents of FB-103 Sink.

Chapter X

CONCLUSIONS

The sedimentary debris from both Cape Monaco and False Bay does not correlate well with the rock types known to exist in the areas. The Cape Monaco Granite is not the dominant material present in the samples. Perhaps the material used in the study was part of the "darker rock" described by Hooper(1962) as occurring between Bonnier and Giard Points. The quartz content is too low and the amphibole content too high for sediment derived from a granite. Tonalite (quartz diorite) is the dominant rock material present in the False Bay area. However, the quartz-poor /amphibole-rich characteristics of the sediments are not diagnostic of tonalite. The glaciers may have passed over a variety of rocks on their way to the point where the samples were collected and, the material that was examined likely was derived from more than just tonalite. Several rock types were noted in the morainal debris along the eastern shore of False Bay (D. Pride, Personal Communication).

The data gathered in the present study should help in working out the geologic histories of both the Cape Monaco and False Bay areas. To date, very little is known of the compositions of material beneath the ice in either of the areas. The Cape Monaco samples have a composition similar to Andesite or Diorite, and the False Bay samples are similar to Andesite in composition as well. Magnetite is the dominant opaque phase present. However,

sphalerite, pyrite, chalcopyrite, and galena also were noted in the samples. Apparently, sulfide mineral systems exist "up glacial stream" in both study areas, systems that could be related to porphyry copper-type mineralization. Further study will be required in both areas before definitive statements can be made. Additional studies initially should include rock outcrop examination and sampling, where possible, plus additional glacial sediment sampling.

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Appendix A

THIN SECTION REPORTS

PETROLOGY REPORT

THIN SECTION #	CM-104-M32 Suspend	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	11	14 points counted.
FELDSPAR	29	32 points counted, sericite in fractures.
BIOTITE	9	12 points counted, some chloritic alteration.
PYROXENE	8	10 points counted, Augite.
AMPHIBOLE	21	24 points counted, Hornblende, partially chlorotized. 3 points counted, Tremolite-Actinolite.
OPAQUES	6	8 points counted.
ACCESSORIES AND ALTERATIONS	16	16 points counted for sericite, limonite staining, chlorite. 4 points counted for secondary epidote.

TOTAL NUMBER OF COUNTS	160
NUMBER OF HOLES COUNTED	34
NUMBER OF GRAINS COUNTED	126

PETROLOGY REPORT

THIN SECTION #	CM-104-M65 Suspend	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	13	78 points counted.
FELDSPAR	37	221 points counted, sericite in fractures.
BIOTITE	10	60 points counted, some chlorotized.
PYROXENE	6	35 points counted, Augite.
AMPHIBOLE	19	107 points counted, Hornblende, partially chlorotized. 6 points counted, Tremolite-Actinolite.
OPAQUES	8	48 points counted.
ACCESSORIES AND ALTERATIONS	7	19 points counted for sericite, limonite staining, chlorite. 19 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	720
NUMBER OF HOLES COUNTED	127
NUMBER OF GRAINS COUNTED	593

PETROLOGY REPORT

THIN SECTION #	CM-104-M115 Suspend	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	4	13 points counted.
FELDSPAR	48	152 points counted, sericite present.
BIOTITE	6	18 points counted, partially chlorotized.
PYROXENE	6	18 points counted, Augite.
AMPHIBOLE	25	68 points counted, Hornblende, some chloritic alteration. 12 points counted Tremolite-Actinolite.
OPAQUES	5	10 points counted.
ACCESSORIES AND ALTERATIONS	6	12 points counted for chlorite, sericite and limonite. 9 points counted for secondary epidote.

TOTAL NUMBER OF COUNTS	371
NUMBER OF HOLES COUNTED	51
NUMBER OF GRAINS COUNTED	320

PETROLOGY REPORT

THIN SECTION #	CM-104-M250 Suspend
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	10	24 points counted.
FELDSPAR	42	105 points counted, sericite present.
BIOTITE	1	2 points counted, chlorotization.
PYROXENE	3	9 points counted, Augite.
AMPHIBOLE	22	55 points counted, Hornblende, partially chlorotized. 1 point counted, Tremolite-Actinolite.
OPAQUES	10	26 points counted.
ACCESSORIES AND ALTERATIONS	12	13 points counted for sericite, chlorite, and limonite. 15 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	261
NUMBER OF HOLES COUNTED	11
NUMBER OF GRAINS COUNTED	250

PETROLOGY REPORT

THIN SECTION #	CM-104-M+250 Suspend	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	3	6 points counted.
FELDSPAR	47	99 points counted, sericite present.
BIOTITE	0.5	1 point counted.
PYROXENE	4	9 points counted, Augite.
AMPHIBOLE	28	58 points counted, Hornblende, less chlorite alteration. 0 points counted for Tremolite-Actinolite.
OPAQUES	12	25 points counted.
ACCESSORIES AND ALTERATIONS	5.5	9 points counted for sericite, chlorite, and limonite. 2 points counted of secondary epidote

TOTAL NUMBER OF COUNTS	209
NUMBER OF HOLES COUNTED	0
NUMBER OF GRAINS COUNTED	209

PETROLOGY REPORT

THIN SECTION #	CM-104-M16 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	4	14 points counted.
FELDSPAR	52	176 points counted, sericite present
BIOTITE	4	12 points counted.
PYROXENE	2	8 points counted, Augite.
AMPHIBOLE	30	102 points counted, Hornblende, some chlorotization. 0 points counted, Tremolite-Actinolite.
OPAQUES	3	11 points counted.
ACCESSORIES AND ALTERATIONS	5	14 points counted for sericite, chlorite, and limonite. 1 point counted for secondary epidote.

TOTAL NUMBER OF COUNTS	519
NUMBER OF HOLES COUNTED	181
NUMBER OF GRAINS COUNTED	338

PETROLOGY REPORT

THIN SECTION # SM-104-M32 Sink

MINERAL	VOL.%	DESCRIPTION
QUARTZ	2	7 points counted.
FELDSPAR	25	84 points counted, sericite present.
BIOTITE	8	27 points counted, partially chloro-tized.
PYROXENE	2	8 points counted, Augite.
AMPHIBOLE	22	71 points counted, Hornblende, chloritic alteration. 3 points counted, Tremolite-Actinolite
OPAQUES	29	98 points counted.
ACCESSORIES AND ALTERATIONS	12	22 points counted for sericite, chlo-rite, and limonite. 25 points counted of secondary epi-dote.

TOTAL NUMBER OF COUNTS	412
NUMBER OF HOLES COUNTED	70
NUMBER OF GRAINS COUNTED	342

PETROLOGY REPORT

THIN SECTION #	CM-104-M32 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	5	11 points counted.
FELDSPAR	24	53 points counted, sericite present.
BIOTITE	4	8 points counted.
PYROXENE	18	40 points counted, Augite.
AMPHIBOLE	34	67 points counted, Hornblende, chloritic alteration. 8 points counted, Tremolite-Actinolite.
OPAQUES	6	13 points counted.
ACCESSORIES AND ALTERATIONS	9	15 points counted for sericite, chlorite, limonite. 7 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	292
NUMBER OF HOLES COUNTED	70
NUMBER OF GRAINS COUNTED	222

PETROLOGY REPORT

THIN SECTION #	CM-104-M65 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	3	7 points counted.
FELDSPAR	36	83 points counted, sericite present.
BIOTITE	3	7 points counted, chlorotized.
PYROXENE	7	17 points counted, Augite.
AMPHIBOLE	40	66 points counted, Hornblende, partially chlorotized. 25 points counted, Tremolite-Actinolite.
OPAQUES	4	10 points counted.
ACCESSORIES AND ALTERATIONS	7	11 points counted for sericite, chlorite, and limonite.

TOTAL NUMBER OF COUNTS	296
NUMBER OF HOLES COUNTED	67
NUMBER OF GRAINS COUNTED	229

PETROLOGY REPORT

THIN SECTION #	CM-104-M115 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	4	8 points counted.
FELDSPAR	35	78 points counted, sericite present.
BIOTITE	6	13 points counted.
PYROXENE	9	19 points counted, Augite.
AMPHIBOLE	32	63 points counted, Hornblende, chloritic alteration. 8 points counted, Tremolite-Actinolite.
OPAQUES	6	14 points counted.
ACCESSORIES AND ALTERATIONS	8	11 points counted for sericite, chlorite, limonite. 6 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	275
NUMBER OF HOLES COUNTED	55
NUMBER OF GRAINS COUNTED	220

PETROLOGY REPORT

THIN SECTION #	CM-104-M250 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	0.5	1 point counted.
FELDSPAR	7.5	19 points counted.
BIOTITE	2	6 points counted.
PYROXENE	7	18 points counted, Augite.
AMPHIBOLE	61	112 points counted, Hornblende, chloritic alteration. 40 points counted, Tremolite-Actinolite.
OPAQUES	14	36 points counted.
ACCESSORIES AND ALTERATIONS	8	8 points counted of sericite and chlorite. 10 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	275
NUMBER OF HOLES COUNTED	25
NUMBER OF GRAINS COUNTED	250

PETROLOGY REPORT

THIN SECTION #	CM-104-M+250 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	0	NO points counted.
FELDSPAR	7	14 points counted, minimal sericite.
BIOTITE	0	NO points counted.
PYROXENE	6.5	13 points counted, Augite.
AMPHIBOLE	57	81 points counted, Hornblende, some chloritic alteration. 33 points counted, Tremolite-Actinolite.
OPAQUES	25.5	51 points counted.
ACCESSORIES AND ALTERATIONS	4	5 points counted for sericite, chlorite, some limonite staining. 3 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	200
NUMBER OF HOLES COUNTED	0
NUMBER OF GRAINS COUNTED	200

PETROLOGY REPORT

THIN SECTION # FB-103-M32 Suspend

MINERAL	VOL.%	DESCRIPTION
QUARTZ	1	2 points counted.
FELDSPAR	45	97 points counted, sericite present.
BIOTITE	0.5	1 point counted.
PYROXENE	1.5	3 points counted, Augite.
AMPHIBOLE	12	23 points counted, Hornblende, some ckloritic alteration. 2 points counted, Tremolite-Actinolite
OPAQUES	38	81 points counted.
ACCESSORIES AND ALTERATIONS	2	4 points counted for sericite and chlorite. 1 point counted of secondary epidote.

TOTAL NUMBER OF COUNTS	244
NUMBER OF HOLES COUNTED	~~130~~
NUMBER OF GRAINS COUNTED	214

THIN SECTION # FB-103-M65 Suspend

MINERAL	VOL.%	DESCRIPTION
QUARTZ	0	NO points counted.
FELDSPAR	38	116 points counted, sericite present.
BIOTITE	1	4 points counted.
PYROXENE	1	3 points counted, Augite.
AMPHIBOLE	9	21 points counted, Hornblende, little chloritic alteration. 5 points counted, Tremolite-Actinolite.
OPAQUES	47	144 points counted.
ACCESSORIES AND ALTERATIONS	4	7 points counted, sericite, chlorite, alot of limonite staining. 3 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	346
NUMBER OF HOLES COUNTED	43
NUMBER OF GRAINS COUNTED	303

PETROLOGY REPORT

THIN SECTION # FB-103-M115 Suspend

MINERAL	VOL.%	DESCRIPTION
QUARTZ	0	NO points counted.
FELDSPAR	34	92 points counted, sericite present.
BIOTITE	0.5	1 point counted.
PYROXENE	1	3 points counted, Augite.
AMPHIBOLE	13.5	33 points counted, Hornblende, chloritic alteration. 4 points counted, Tremolite-Actinolite.
OPAQUES	48	130 points counted.
ACCESSORIES AND ALTERATIONS	3	7 points counted, sericite, chlorite, alot of limonite staining.

TOTAL NUMBER OF COUNTS	282
NUMBER OF HOLES COUNTED	9
NUMBER OF GRAINS COUNTED	273

PETROLOGY REPORT

THIN SECTION #	FB-103-M+250 Suspend	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	8	20 points counted.
FELDSPAR	36	96 points counted, sericite present.
BIOTITE	0	NO points counted.
PYROXENE	1	2 points counted, Augite.
AMPHIBOLE	31	78 points counted, Hornblende, chloritic alteration. 3 points counted, Tremolite-Actinolite.
OPAQUES	20	53 points counted.
ACCESSORIES AND ALTERATIONS	4	5 points counted, sericite, chlorite, limonite. 5 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	262
NUMBER OF HOLES COUNTED	0
NUMBER OF GRAINS COUNTED	262

PETROLOGY REPORT

THIN SECTION # FB-103-M16 Sink		
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	0	NO points counted.
FELDSPAR	43	44 points counted, sericite present in fractures.
BIOTITE	0	NO points counted.
PYROXENE	2	2 points counted, Augite.
AMPHIBOLE	23	20 points counted, Hornblende, some chloritic alteration. 4 points counted, Tremolite-Actinolite.
OPAQUES	28	29 points counted.
ACCESSORIES AND ALTERATIONS	4	4 points counted, sericite, chlorite, limonite. 0 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	114
NUMBER OF HOLES COUNTED	11
NUMBER OF GRAINS COUNTED	103

PETROLOGY REPORT

THIN SECTION # FB-103-M32 Sink

MINERAL	VOL.%	DESCRIPTION
QUARTZ	2	6 points counted.
FELDSPAR	39	118 points counted, alot of sericite present.
BIOTITE	0.3	1 point counted.
PYROXENE	3.7	11 points counted, Augite.
AMPHIBOLE	31	87 points counted, Hornblende, chloritic alteration present. 7 points counted, Tremolite-Actinolite.
OPAQUES	21	65 points counted.
ACCESSORIES AND ALTERATIONS	3	6 points counted, sericite, chlorite, limonite. 2 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	336
NUMBER OF HOLES COUNTED	33
NUMBER OF GRAINS COUNTED	303

PETROLOGY REPORT

THIN SECTION # FB-103-M65 Sink

MINERAL	VOL.%	DESCRIPTION
QUARTZ	0.6	2 points counted.
FELDSPAR	29	83 points counted, sericite present.
BIOTITE	0.4	1 point counted.
PYROXENE	5	15 points counted, Augite.
AMPHIBOLE	38	83 points counted, Hornblende, chloritic alteration present.
OPAQUES	23	65 points counted.
ACCESSORIES AND ALTERATIONS	4	6 points counted, sericite, chlorite, limonite staining.

TOTAL NUMBER OF COUNTS	327
NUMBER OF HOLES COUNTED	45
NUMBER OF GRAINS COUNTED	282

PETROLOGY REPORT

THIN SECTION #	FB-103-M115 Sink	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	0	NO points counted.
FELDSPAR	30	84 points counted, sericite present.
BIOTITE	0	NO points counted.
PYROXENE	2	5 points counted, Augite.
AMPHIBOLE	47	123 points counted, Hornblende, chloritic alteration. 9 points counted, Tremolite-Actinolite.
OPAQUES	19	55 points counted.
ACCESSORIES AND ALTERATIONS	2	2 points counted of sericite, chlorite, limonite. 2 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	285
NUMBER OF HOLES COUNTED	3
NUMBER OF GRAINS COUNTED	282

PETROLOGY REPORT

THIN SECTION # FB-103-M250 Sink		
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	2	6 points counted.
FELDSPAR	10	29 points counted, minor sericite.
BIOTITE	0.4	1 point counted.
PYROXENE	1	3 points counted, Augite.
AMPHIBOLE	49	135 points counted, Hornblende, chloritic alteration. 3 points counted, Tremolite-Actinolite.
OPAQUES	31	88 points counted.
ACCESSORIES AND ALTERATIONS	6.6	2 points counted, sericite, chlorite, limonite. 15 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	283
NUMBER OF HOLES COUNTED	1
NUMBER OF GRAINS COUNTED	282

PETROLOGY REPORT

THIN SECTION #	FB-103-M250 Suspend	
MINERAL	**VOL.%**	**DESCRIPTION**
QUARTZ	0.5	1 point counted.
FELDSPAR	27.5	57 points counted, sericite present.
BIOTITE	0	NO points counted.
PYROXENE	1	2 points counted, Augite.
AMPHIBOLE	18	34 points counted, Hornblende, some chloritic alteration. 3 points counted, Tremolite-Actinolite.
OPAQUES	51	107 points counted.
ACCESSORIES AND ALTERATIONS	2	5 points counted of sericite, chlorite, alot of limonite staining. 0 points counted secondary epidote.

TOTAL NUMBER OF COUNTS	210
NUMBER OF HOLES COUNTED	2
NUMBER OF GRAINS COUNTED	208

PETROLOGY REPORT

THIN SECTION # FB-103-M+250

MINERAL	VOL.%	DESCRIPTION
QUARTZ	0	NO points counted.
FELDSPAR	12	32 points counted, sericite present.
BIOTITE	0	NO points counted.
PYROXENE	1.5	5 points counted, Augite.
AMPHIBOLE	36	93 points counted, Hornblende, chloritic alteration. 6 points counted, Tremolite-Actinolite.
OPAQUES	49	134 points counted.
ACCESSORIES AND ALTERATIONS	1.5	2 points counted, sericite, limonite. 3 points counted of secondary epidote.

TOTAL NUMBER OF COUNTS	275
NUMBER OF HOLES COUNTED	0
NUMBER OF GRAINS COUNTED	275

Appendix B

PLAGIOCLASE COMPOSITION

TABLE 7

Sample	Extinction Angle	Anorthite Composition
CM-104-M32 Suspend	14'	32
CM-104-M65 Suspend	27.5'	49
CM-104-M65 Suspend	15'	31
CM-104-M65 Suspend	13'	30.5
CM-104-M65 Suspend	7.5'	27
CM-104-M65 Suspend	111'	29
CM-104-M115 Suspend	8.5'	26
CM-104-M115 Suspend	9'	27
CM-104-M16 Sink	8.5'	26
CM-104-M16 Sink	18.5'	35

AVERAGE AN CONTENT= 33.6 (Andesine)

TABLE 8

Sample	Extinction Angle	Anorthite Composition
FB-103-M16 Sink	8.5'	26
FB-103-M32 Suspend	17'	35
FB-103-M32 Suspend	19'	37
FB-103-M32 Suspend	21'	40
FB-103-M32 Suspend	17'	35
FB-103-M32 Sink	22.5'	42
FB-103-M32 Sink	21'	40
FB-103-M65 Sink	10.5'	28
FB-103-M65 Sink	24'	44
FB-103-M65 Sink	27.5'	49

AVERAGE AN CONTENT= 37.6 (Andesine)

Appendix C

POLISHED SURFACE REPORTS

OPAQUE PETROLOGY REPORT

SAMPLE #CM-104-M16 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	92	266 counts.
Hematite	5.5	16 counts.
Chalcopyrite	2.5	6 counts.
TOTAL NUMBER OF MINERAL COUNTS		289 counts.

COMMENTS:

Hematite after magnetite, attached and around periphery of magnetite grains.

OPAQUE PETROLOGY REPORT

SAMPLE # Cm-104-M65 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	82	246 counts.
Hematite	12.3	37 counts.
Sphalerite	2.7	8 counts.
Pyrite	0.7	2 counts.
Chalcopyrite	2	7 counts.
Galena	0.3	1 count.
TOTAL NUMBER OF MINERAL COUNTS		301 counts.

COMMENTS:

Hematite after magnetite, usually around magnetite. Small grains of chalcopyrite.

OPAQUE PETROLOGY REPORT

SAMPLE # CM-104-M115 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	85	259 counts.
Sphalerite	6.9	21 counts.
Hematite	6.6	20 counts.
Pyrite	1	3 counts.
Chalcopyrite	0.5	2 counts.
TOTAL NUMBER OF MINERAL COUNTS		305 counts.

COMMENTS:

Chalcopyrite in magnetite at times. Pyrite in discrete grains. Secondary hematite usually surrounding magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # CM-104-M250 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	77	235 counts.
Sphalerite	9	30 counts.
Hematite	8.2	25 counts.
Pyrite	3.6	8 counts.
Galena	1.2	4 counts.
Chalcopyrite	1	2 counts.
TOTAL NUMBER OF MINERAL COUNTS		304 counts.

COMMENTS:

Hematite after magnetite, attached to magnetite Pyrite in discrete grains. Sphalerite is sometimes attached to magnetite. Chalcopyrite in discrete grains.

OPAQUE PETROLOGY REPORT

SAMPLE # CM-104-M250 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	91	279 counts.
Hematite	5.5	17 counts.
Sphalerite	2.6	8 counts.
Chalcopyrite	0.9	2 counts.
Pyrite	0.3	1 count.
TOTAL NUMBER OF MINERAL COUNTS		307 counts.

COMMENTS:

Hematite after magnetite, chalcopyrite in small grains contained inside magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # CM-104-M+250 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	87.5	261 counts.
Hematite	6.3	19 counts.
Pyrite	2.3	7 counts.
Sphalerite	3	9 counts.
Chalcopyrite	0.9	2 counts.
TOTAL NUMBER OF MINERAL COUNTS		298 counts.

COMMENTS:

Secondary hematite frequently surrounding magnetite. Pyrite and chalcopyrite in discrete grains. Sphalerite sometimes attached to magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # CM-104-M+250 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	91.7	276 counts.
Sphalerite	3.6	11 counts.
Pyrite	2.3	7 counts.
Chalcopyrite	1.4	4 counts.
Hematite	1	3 counts.
TOTAL NUMBER OF MINERAL COUNTS		301 counts.

COMMENTS:

Secondary hematite present. Chalcopyrite and pyrite discrete, sometimes closely assoc. with magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE #FB-103-M16 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	77	238 counts.
Hematite	18.5	57 counts.
Chalcopyrite	4.2	13 counts.
Pyrite	0.3	1 count.
TOTAL NUMBER OF MINERAL COUNTS		309 counts.

COMMENTS:

Secondary hematite surrounding magnetite.
Chalcopyrite is granulated at times.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M32 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	86.7	289 counts.
Hematite	13.2	44 counts.
TOTAL NUMBER OF MINERAL COUNTS		333 counts.

COMMENTS:

Hematite after magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M65 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	74	247 counts.
Hematite	24	80 counts.
Sphalerite	1.4	6 counts.
Pyrite	0.6	2 counts.
TOTAL NUMBER OF MINERAL COUNTS		334 counts.

COMMENTS:

Hematite after magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M65 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	80.4	246 counts.
Hematite	16.3	50 counts.
Sphalerite	3.3	10 counts.
TOTAL NUMBER OF MINERAL COUNTS		306 counts.

COMMENTS:

Secondary hematite surrounding magnetite.
Sphalerite in discrete grains.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M115 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	79.2	255 counts.
Hematite	16.5	53 counts.
Sphalerite	3.4	11 counts.
Pyrite	0.6	2 counts.
Chalcopyrite	0.3	1 count.
TOTAL NUMBER OF MINERAL COUNTS		322 counts.

COMMENTS:

Hematite after magnetite, chalcopyrite is fragmented and in closely associated contact to magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M115 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	77.5	275 counts.
Hematite	16.6	59 counts.
Pyrite	3.1	11 counts.
Sphalerite	2.3	8 counts.
Chalcopyrite	0.5	2 counts.
TOTAL NUMBER OF MINERAL COUNTS		355

COMMENTS:

Secondary hematite surrounding magnetite.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M250 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	76	257 counts.
Hematite	19.5	66 counts.
Sphalerite	3.2	11 counts.
Chalcopyrite	1	3 counts.
Pyrite	0.3	1 count.
TOTAL NUMBER OF MINERAL COUNTS		338 counts.

COMMENTS:

Hematite after magnetite. Chalcopyrite in granulated form.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M250 Sink		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	70.6	226 counts.
Hematite	24.6	79 counts.
Sphalerite	2.8	9 counts.
Pyrite	1	3 counts.
Chalcopyrite	0.9	3 counts.
TOTAL NUMBER OF MINERAL COUNTS		320 counts.

COMMENTS:

Secondary hematite surrounding magnetite.
Pyrite and sphalerite in discrete grains.

OPAQUE PETROLOGY REPORT

SAMPLE # FB-103-M+250		
OPAQUE MINERAL	**%**	**# OF COUNTS**
Magnetite	93.5	300 counts.
Sphalerite	3.1	10 counts.
Hematite	1.9	6 counts.
Pyrite	0.9	3 counts.
Chalcopyrite	0.6	2 counts.
TOTAL NUMBER OF MINERAL COUNTS		321 counts.

COMMENTS:

Hematite after magnetite. Sphalerite sometimes attached to magnetite. Pyrite discrete.